Exhibit 8

PATENT SPECIFICATION

1,021,797

DRAWINGS ATTACHED.

1,021,797

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Int. Cl.:—G 05 b, c, d //F 04 d.

COMPLETE SPECIFICATION.

Method and Apparatus for the Protection of a Centrifugal Compressor.

We, SHELL INTERNATIONALE RESEARCH MAATSCHAPPIJ N.V., a Company organised under the Laws of the Netherlands, of 30 Carel van Bylandtlaan, The Hague, The Netherlands, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates to a method and apparatus for the protection of a centrifugal compressor in order to prevent entirely or almost entirely the so-called surging of the compressor. Surging may occur in a compressor when, at a certain pump pressure, the gas velocity through the compressor becomes too low, or when, at a certain gas velocity the pressure becomes too high. In order to counteract this surging the compressor is provided with a by-pass or a blow-off line, which during normal operation (i.e. when the gas load is sufficiently high), is closed by a control valve. As soon as the risk or surging arises, the valve is opened to a greater or lesser extent, so that the gas flow through the compressor increases and surging is avoided. Since the by-passing or the blow-off of gas through the by-pass or the blow-off line represents a loss, in any case a loss of power, the valve is only opened when and insofar as it is necessary to avoid surging.

It has already been proposed to operate the control valve by a control system, to which signals dependent on the pressure level of the compressor and of the gas flow through the compressor are supplied. Thus, for example according to U.S. patent specification 2,000,721, a signal proportional to the discharge pressure of the compressor, is compared in the controller, which controls the position of the control valve, with the sum of two signals, one of which depends on the flow rate of the gas feed and the other being dependent on the flow rate of the gas stream in the by-pass.

This control system can at best only work well at a single pressure level, i.e. the pressure level at which the controller has been set. If the suction pressure varies, it would be necessary, in order to obtain an effective protection against surging, continually to alter the setting of the controller, this being almost impracticable.

Hence, when the inlet pressure of the gas to be compressed is not constant or substantially constant, which often occurs when a plurality of compressors are connected in series, no effective protection of the compressor against surging is possible.

The invention now provides a method by means of which an effective protection against surging is obtained, which is practically independent of the pressure level at which the compressor operates. Moreover the protection is likewise independent or substantially independent of the inlet temperature of the gas to be compressed.

Special embodiments of the protection according to the invention also afford the possibility of making the compressor operate safely without or substantially without loss of power almost up to the range in which surging may occur. This is particularly important when the gas load of the compressor varies considerably. It is then particularly advantageous, when the range within which the gas load can vary without loss is as wide as possible. However, when, as the result of a gas load which is too low (or pressure which is too high), operations cannot be conducted without loss, the loss is kept at a minimum while at the same time a stable control of the control valve is ensured.

According to the present invention the throughput of the control valve is controlled by the output signal of a controller which

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compares a set value with input signal being the quotient of two signals one of which (Δp) is dependent on the gas flow through the compressor and the other (p) is dependent on the pressure level of the compressor, the direction of action of the control being such that—when $\frac{\Delta p}{p}$ or $\frac{p}{\Delta p}$ attains a value which is respectively smaller or greater than the set value of the controller—the controller produces an output signal in the valve-opening sense.

The signal dependent on the gas flow through the compressor is as a rule a differential pressure signal measured across an orifice, a venturi or a similar device.

Preferably the signal dependent on the gas flow through the compressor is measured at the discharge side of the compressor. The signal dependent on the pressure level is preferably obtained by measuring the discharge pressure of the compressor. Good results are obtained by a combination of Δp measured at the suction side of the compressor (Δp_1) with p measured at the discharge side of the compressor (p_2), or vice versa (Δp_2 and p_1). In practice the best control is achieved by measuring both Δp and p at the discharge side of the compressor (thus with the combination of Δp_2 and p_2).

By changing the set value of the controller, the moment at which the control valve begins to open may be brought closer to the surge limit of the compressor or may be further removed therefrom.

The method according to the invention is particularly useful when the gas load is normally well outside the danger area (this is the area in which surging of the compressor would occur if the control valve were closed) and does not vary very much. In this case the controller is usually provided with proportional action only and moreover with a wide proportional band. The wide proportional band is necessary for a stable control. If an unexpected deviation from the normal state now occurs, for example because the discharge of compressed gas becomes blocked, the controller prevents surging.

However, when the normal operation of the compressor entails a considerable variation in the load and thereby comes close to or exceeds the surge limit (so that the control valve has to act repeatedly or is permanently in action in order to avoid surging) the protection by means of a controller with proportional action only is less satisfactory: as a result of the relatively great width of the proportional band of the controller, the control is not very economic. If, however, an improvement in the economy were attempted by the introduction of integral action, the compressor may run risks when there are rapid variations in the load.

According to another characteristic of the invention it is therefore desirable to use two controllers connected in parallel, one of which has proportional action only and moreover a relatively narrow proportional band, while the other has both proportional and integral action and moreover a relatively wide proportional band; the output signals of these controllers are passed to an auxiliary relay, which causes the control valve to be controlled only by that signal which at any moment would impart the greatest throughput to the control valve.

As a rule both controllers will be connected to the same dividing circuit or relay (circuit or relay which supplies the quotient $\Delta p/p$ or $p/\Delta p$); in principle, however, it is possible to use various dividing circuits or relays, in order to determine and use various quotients (for example $\frac{\Delta p_2}{p_2}$ and $\frac{\Delta p_2}{p_1}$).

A similar result may be achieved by using a single controller, which in addition to proportional and integral action also has derivative action and preferably a wide proportional band.

The protection system according to the invention may be carried out in various ways, for example hydraulically, pneumatically or electrically; a pneumatic embodiment is often used. If a pneumatic embodiment is employed the output signal of the auxiliary relay (which is used in the control system having two controllers)—if necessary after amplification—may be used in order to feed that part of the controller, which produces the integral action, with which one of the controllers is provided.

Further, an apparatus may be used in a manner otherwise known per se, which prevents the controller from becoming saturated as a result of the integral action (so-called "anti reset wind-up").

The invention may be carried into practice in various ways but it will now be further illustrated by way of example with reference to the accompanying drawings in which:

Figure 1 relates to the use of a single controller and

Figure 2 to the use of two controllers connected in parallel.

Figure 1 shows diagrammatically a method for the compression of natural gas by means of a centrifugal compressor 1. The gas is supplied through a line 2 and leaves the compressor through a line 3. The compressed gas is subsequently cooled by means of a cooler 4 and is freed in a separator 5 from any condensate which may have been formed. The condensate is discharged through a line 6 and the compressed gas through lines 7 and 8, after which it may be pumped back to the earth formation or passed to an installation where liquid methane is prepared. A gas

by-pass 9 connects the lines 7 and 2; a control valve 10, which is normally closed, is incorporated in this by-pass. If surging of the compressor occurs or if there is a danger of surging, the control valve is opened so that surging is eliminated or prevented. The by-pass 9 could have been connected to the discharge side of the compressor at an earlier point, for example, just before the cooler 4.

In the line 3 an orifice 11 is inserted (which may be a venturi or similar device) which is connected to a differential pressure meter 12. This meter produces a signal (Δp_2), which is proportional to the differential pressure occurring across the orifice. A pressure meter 13 is likewise connected to the line 3 and produces the signal (p_2) which is proportional to the discharge pressure of the compressor.

The signals of the meters 12 and 13 are passed to a dividing circuit or relay 14, the output signal of which is proportional to $\frac{\Delta p_2}{p_2}$. This signal is supplied to a controller 15 which at 16 may be set at a certain value of a quotient (A) which is otherwise adjustable according to magnitude. The controller is preferably only provided with proportional action. The controller 15 compares the measured value (originating from the dividing relay 14) of the quotient $\frac{\Delta p_2}{p_2}$ with the set value A. The output signal 17 of the controller 15 controls the control valve 10. If $\frac{\Delta p_2}{p_2} \geqslant A$ the control valve 10 is or remains closed. When, however, $\frac{\Delta p_2}{p_2} < A$ (for example, owing to the fact that no gas or less gas than usual is withdrawn at 8) the control valve is opened to a greater or lesser degree, in any case to such an extent that no surging of the compressor occurs. By altering the set value A, the moment at which the control valve 10 begins to open is shifted.

This protection of the compressor has the advantage of being practically independent of the compressor pressure. When there is a change in the pressure level, for example when there is a rise or fall in the pressure of the natural gas fed, the protection against surging continues to operate without anything having to be changed.

In the pneumatic embodiment the signal pressure (17) is in general so chosen that when the signal pressure disappears the valve 10 is opened.

The quotient $\frac{p_2}{\Delta p_2}$ could have been used instead of the quotient $\frac{\Delta p_2}{p_2}$ and the former could have been passed to the controller 15. The set value then changes, as does the direction of the control. In this case the valve is, of course, opened as soon as $\frac{p_2}{\Delta p_2}$ becomes greater than the set value A^1 where $A^1 = \frac{1}{A}$.

Figure 2 shows the changes which are necessary when using two controllers 15*a* and 15*b* connected in parallel and both connected to the same dividing relay 14. The controller 15*a* only has proportional action and is moreover adjusted to at a relatively narrow proportional band (for example 10%). The controller 15*b* has both proportional and integral action and moreover a wide (compared with controller 15*a*) proportional band (for example 100 to 250%). The set values 16*a* and 16*b* of the controllers respectively, differ slightly, in such a way that the controller 15*b* can first come into action. The control range of the controller 15*a* lies on that side of the operating line of the controller 15*b* where the surge limit also lies and usually near to the said operating line (at the operating line applies: $\frac{\Delta p}{p} = A$).

The output signals of the controllers are now passed to an auxiliary relay 18 which only allows that signal to pass through which at any moment would impart the greatest throughput to the control valve 10. In the present embodiment (in which the control valve closes when the pneumatic signal 17 increases in magnitude) this means that the relay 18 continually transmits the smaller of the two signals from the controllers 15*a*, 15*b*.

The part 16*c* of the controller 15*b* which relates to the integral action thereof is preferably fed by the output signal of the relay 18. In Figure 2 the signal 17 is therefore passed to the said part via an amplifier 19. This results in a more rapid operation of the integral action. Further an apparatus is generally used which prevents the controller from becoming saturated as a result of the integral action (anti reset wind-up).

If the load of the compressor 1 (in so far as it concerns the discharge at 8) approaches the surge limit, the controller 15*b* first comes into action since the relevant operating line is the first to be overshot. Since the operating line of controller 15*b* can be placed relatively close to the surge limit the operation of the compressor installation remains economic; for losses as a result of by-passing of gas through the by-pass do not occur as long as the operating line of controller 15*b* (in so far

as it concerns the discharge at 8) is not overshot, since the control valve is then closed; and the control valve is only slightly opened when the operating line is only slightly overshot, so that the losses are small.

If, however, a further change in the load brings the compressor closer to or in the danger area, the other controller 15*a* can immediately come into operation and open the control valve forthwith. Without this controller 15*a* there is, however, a great risk of surging of the compressor, since the controller 15*b*, as a result of the wide proportional band and the action resulting from the integral action, cannot open the control valve 10 in time.

On the other hand a permanent unstable control (owing to the narrow proportional band of controller 15*a*) need not be feared, since eventually the controller 15*b* reassumes control, viz. as soon as the integral action has been able to build up a signal of suitable magnitude.

Finally, the integral action also ensures that, when the compressor must operate permanently with a more or less widely opened control valve, no difference between measured value and set value occurs which could otherwise lead to surging of the compressor.

WHAT WE CLAIM IS:—

1. A method of preventing surging of a centrifugal compressor wherein a by-pass or blow-off line for the gas is provided with a control valve, the throughput of which is controlled by the output signal of a controller which compares a set value with an input signal being the quotient of two signals one of which (Δp) is dependent on the gas flow through the compressor and the other (p) is dependent on the pressure level of the compressor, the direction of action of the control being such that—when $\frac{\Delta p}{p}$ or $\frac{p}{\Delta p}$ attains a value which is respectively smaller or greater than the set value of the controller—the controller produces an output signal in the valve-opening sense.

2. A method as claimed in Claim 1 wherein the signal dependent on the gas flow through the compressor is measured as a differential pressure signal across an orifice, a venturi or a similar device.

3. A method as claimed in Claims 1 or 2, wherein the signal dependent on the gas flow through the compressor is measured at the discharge side of the compressor.

4. A method as claimed in any one of the preceding claims wherein the signal dependent on the pressure level is obtained by measuring the discharge pressure of the compressor.

5. A method as claimed in any one of the preceding claims wherein the controller has proportional, integral and derivative action.

6. A method as claimed in any one of Claims 1 to 4, wherein two controllers connected in parallel are used, one of which has only proportional action and moreover a relatively narrow proportional band, while the other has both proportional action and integral action and in addition a relatively wide proportional band; and that the output signals of these controllers are passed to an auxiliary relay, which causes the control valve to be controlled only by that signal which at any moment would impart the greatest throughput to the control valve.

7. An apparatus suitable for the protection of a centrifugal compressor in the manner described in any one of the preceding claims, comprising a pressure meter for the pressure level of the compressor and a differential pressure meter for the gas flow through the compressor, a dividing relay which is connected to receive the outputs of these meters, a controller which is connected to receive from the dividing relay an output comprising the value of the quotient of differential pressure and pressure and to compare this quotient with the set value and a connection for connecting the output of the dividing relay to a control system of the control valve.

8. An apparatus as claimed in Claim 7, in which the controller has proportional, integral and derivative action.

9. An apparatus as claimed in Claim 7, including two controllers both of which are connected to a dividing relay, one of these controllers having only proportional action and moreover a relatively narrow proportional band, the other having both proportional and integral action and in addition a relatively wide proportional band; a connection between the output of each of the controllers and an auxiliary relay which is capable of selecting from the two signals supplied thereto that signal which would impart at any moment the greatest throughput to the control valve, and by a connection for connecting the output of the auxiliary relay to the control system of the control valve.

10. An apparatus as claimed in Claim 9 including a connection from the integrating part of the controller having integral action, if necessary via an amplifier, to the output of the auxiliary relay.

11. An apparatus as claimed in Claim 9 or 10, characterized by means for avoiding saturation of the controller by the influence of the integral action.

12. A method of preventing surging of a centrifugal compressor substantially as described herein with reference to Figure 1 or Figure 2 of the accompanying drawings.

13. Apparatus for preventing surging of a

centrifugal compressor substantially as described herein with reference to Figure 1 or Figure 2 of the accompanying drawings.

KILBURN & STRODE,
Chartered Patent Agents,
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Published at The Patent Office, 25 Southampton Buildings, London, W.C.2,
from which copies may be obtained.

1021797 COMPLETE SPECIFICATION

1 SHEET *This drawing is a reproduction of the Original on a reduced scale*

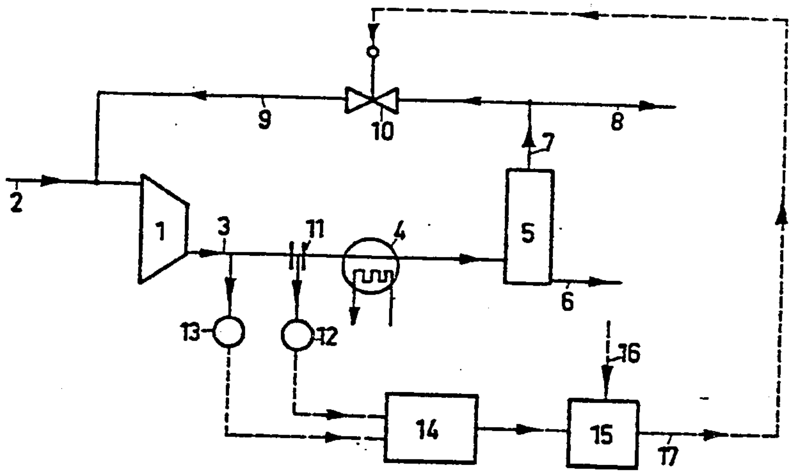


FIG.1

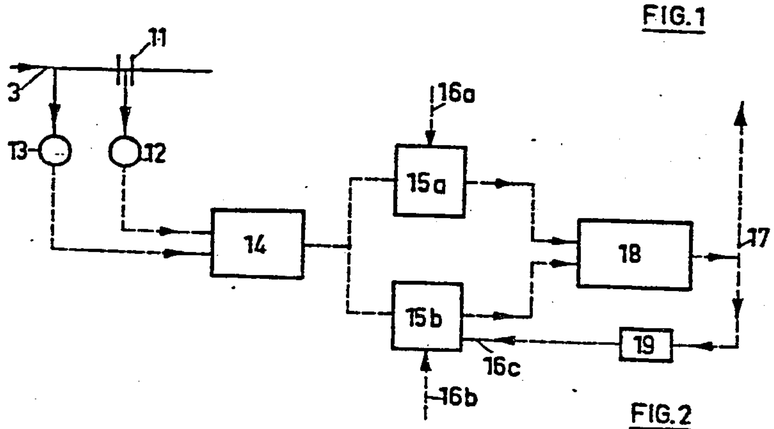


FIG.2

Exhibit 9

A. C. E. RATEAU.

AUTOMATIC RELIEF VALVE FOR FLUID IMPELLING APPARATUS.

APPLICATION FILED NOV. 20, 1906.

1,052,172. Patented Feb. 4, 1913.

Fig. 1.

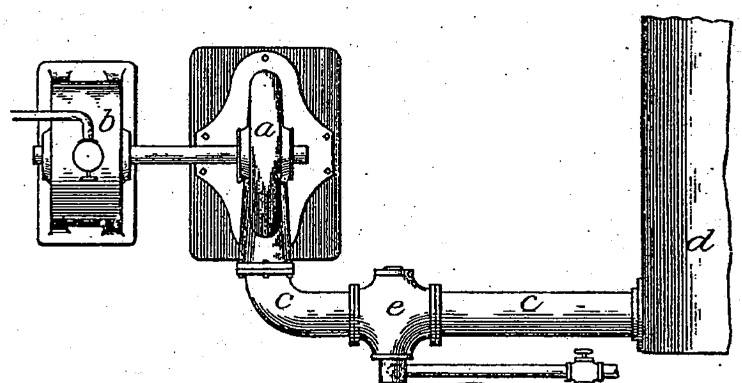


Fig. 2.

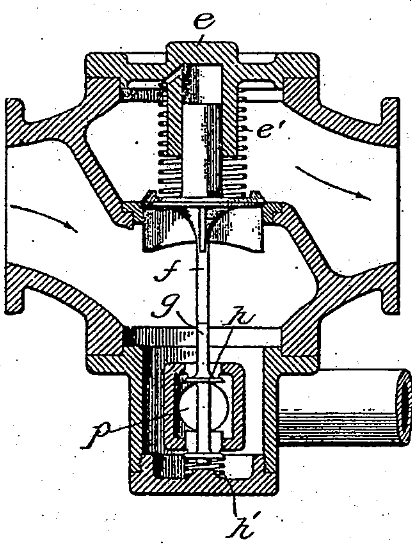
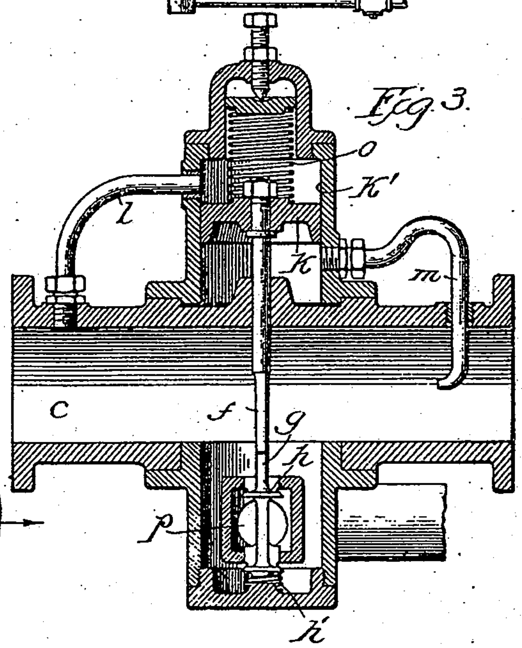


Fig. 3.



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REMAND
PTX 1015

RMD AS 000164

UNITED STATES PATENT OFFICE.

AUGUSTE CAMILLE EDMOND RATEAU, OF PARIS, FRANCE.

AUTOMATIC RELIEF-VALVE FOR FLUID-IMPELLING APPARATUS.

1,052,172. Specification of Letters Patent. Patented Feb. 4, 1913.

Application filed November 20, 1906. Serial No. 344,351.

To all whom it may concern:

Be it known that I, AUGUSTE CAMILLE EDMOND RATEAU, citizen of the Republic of France, residing at Paris, France, have invented a certain new and useful Improvement in Automatic Relief-Valves for Fluid-Impelling Apparatus, of which the following is a full, clear, concise, and exact description.

My invention relates to an automatic relief-valve for fluid impelling apparatus, and its object is more particularly to provide means for preventing surging and vibration in compressors of the turbine type, *i. e.*, centrifugal or helicoidal compressors. In the use of centrifugal impellers for compressing elastic fluid, such as air or gas, at high pressures, one of the difficulties encountered is that the current of air or gas becomes pulsatory or surging when the discharge is relatively weak. For example, in the case of a centrifugal compressor receiving air from the atmosphere and discharging it into a reservoir where the air is already under pressure, it is necessary to provide between the reservoir and the compressor a check-valve which automatically closes to prevent back-flow from the reservoir when the pressure from the compressor is insufficient. If this check-valve closes while the compressor remains in operation, the elastic fluid takes on a pulsatory or surging movement, going and coming alternately at variable periods of time according to circumstances. Violent vibrations and shocks are thus set up in the apparatus, and these will persist until the discharge of air reaches a high pressure sufficient to hold the check-valve open. Such surging and vibration, furthermore, occasion a considerable loss of energy, which is manifested in the heating of the air and of the machine itself. To overcome this difficulty, the present invention contemplates the provision of means for opening an independent outlet for the discharge when the working load becomes of such value as would tend to set up surging or vibration.

I will describe my invention more particularly by reference to the accompanying drawings, in which—

Figure 1 is a diagrammatic illustration of a centrifugal fan or compressor discharging through a pipe leading to a reservoir, the discharge pipe being equipped with a check-valve having also an automatic relief-valve associated therewith; Fig. 2 is a detail sectional view of the relief-valve; and Fig. 3 is a detail view of another form of the invention, in which the relief valve is arranged to be actuated by a piston controlled by variations in the amount of fluid flavoring in the discharge duct, independent of any action of the check-valve.

Like parts are designated by similar letters of reference throughout the several views.

Referring first to Fig. 1, the centrifugal fan or compressor *a* driven by the turbine engine *b*, draws air from the atmosphere and discharges into the pipe *c* which leads to a reservoir *d*. A combined check and automatic relief-valve is interposed in the pipe *c*, the detailed construction thereof being clearly shown in Fig. 2. The check-valve *e* is arranged with a reciprocating valve-stem *f* adapted to abut against the valve-stem *g* of the relief-valve *h*. A spring h^1 tends normally to press the relief-valve against its seat to close the independent outlet *p*. The check valve is also provided with a spring e^1 tending to press it against its seat and thus to close the normal discharge passage to the reservoir *d*. The spring e^1 upon the check valve is stronger than the opposing spring h^1 upon the relief-valve, so that the check-valve in closing will open the relief-valve against the tension of said spring h^1. When the discharge from the compressor *a* is strong enough to raise the check-valve from its seat, the pressure of its stem against the stem of the relief-valve is removed, permitting the latter to be closed by the spring h^1.

The fluid discharged through the independent outlet *p* controlled by the relief-valve may be simply exhausted into the atmosphere, or if it is a gas to be saved, it may be led back through a pipe to the intake of the compressor. The discharge pipe for the independent outlet may be provided with a valve, if desired, to control the flow therethrough.

It will be understood that the flow through the independent outlet *p* is restricted, as by means of the valve in the discharge pipe connected thereto, and the small size of the latter in comparison with the discharge pipe *c*, to prevent an undesirable lowering of the pressure on the outlet side of the compressor when the independent outlet is open.

With apparatus described, the volume of fluid taken by the absorbing apparatus *d* of Fig. 1, plus the volume of fluid passing through the relief outlet *p*, is never less than a definite minimum which should exceed the volume of flow, determined by experience or experiments, at which the blower is liable to give undesirable pulsations in flow.

In the construction shown in Fig. 2, the relief valve *h* is operated by a check valve which is adapted to perform the usual function of a check or non-return valve. It is apparent, however, that in so far as the present invention is concerned, the essential characteristic of the operating device for the relief valve *h* employed in Fig. 2, is not its capacity for directly preventing back flow through the main delivery duct, but in its capacity for changing its position as the volume of flow through the main delivery duct varies, so that the relief valve *h* is operated in response to variations in the volume or quantity of fluid flowing through the main delivery duct.

It is apparent, of course, that means quite different from that shown in Fig. 2 might be employed for operating the relief valve in response to variations in the volume of flow through the main delivery duct, and in Fig. 3 I have illustrated a construction in which the relief-valve instead of being operated directly by the check-valve, has its stem connected to a piston K working in a cylinder K^1 in response to changes in pressure thereon. The upper face of the piston is subjected to the static pressure in the discharge duct *c*, conveyed through a tube *l*, while the lower face of said piston is subjected to a pressure equal to the static pressure of the fluid plus its dynamic pressure due to velocity, which combined pressure is made manifest by a Pitot tube *m* having its open end facing the stream of fluid in the pipe, and communicating at its other end with the cylinder K^1 underneath the piston. In this arrangement, when the velocity of the fluid in the pipe *c* falls below a predetermined point, a spring *o*, acting downwardly on the piston K will overcome the pressure conveyed to the Pitot tube *m* and will force open the relief-valve. A subsequent increase in the velocity of the fluid will cause the pressure on the lower face of the piston to increase until the tension of said spring *o* will be overcome and the relief-valve again closed.

In the operation of the compressor equipped with a relief-valve such as above described, when the check-valve is closed, or when for any reason the pressure conditions are such as would ordinarily give rise to surging, the opening of the supplementary outlet provides for a continuous efflux of fluid sufficient to suppress any such tendency.

I claim:—

1. The combination with a fluid impeller of the turbine type and a duct receiving the discharge from said impeller, of a restricted relief outlet opening from said duct, a relief valve arranged to open and close said outlet and actuating means for said valve responsive to the volume of flow through said duct and adapted to open and close said valve as said volume decreases from and rises to a predetermined amount.

2. The combination with a fluid impeller of the turbine type and a reservoir, of a pipe receiving the discharge from said compressor and leading to said reservoir, said pipe having an independent outlet, a valve controlling said independent outlet, and means acted upon positively by the static pressure of the discharge and the dynamic pressure thereof, arranged to operate said valve in accordance with the amount of fluid discharged by the compressor.

3. An automatic relief valve apparatus, comprising a pipe having a relief opening, a valve controlling said relief opening, a chamber having a movable part, sensitive to fluid pressure, connected to said valve to operate the same, a tube conveying the static pressure in the pipe to one side of said movable part, and a second tube transmitting the total pressure of the fluid, both static and dynamic, and connected with said chamber on the opposite side of said movable part.

4. The combination with a centrifugal compressor, of a pipe receiving the discharge from said compressor and leading to a reservoir, said pipe having an independent outlet, a valve controlling said independent outlet, and means acted upon oppositely by the static pressure of the discharge and the dynamic pressure thereof, arranged to operate said valve.

5. An automatic relief-valve apparatus for pipes comprising a valve controlling a relief-opening, a chamber having a movable part, sensitive to fluid pressure, connected to said valve to operate the same, a tube conveying the static pressure in the pipe to one side of said movable part, and a Pitot tube in said pipe, connected with said chamber on the opposite side of said movable part.

In witness thereof I hereunto subscribe my name this 5th day of August, A. D. 1908.

AUGUSTE CAMILLE EDMOND RATEAU.

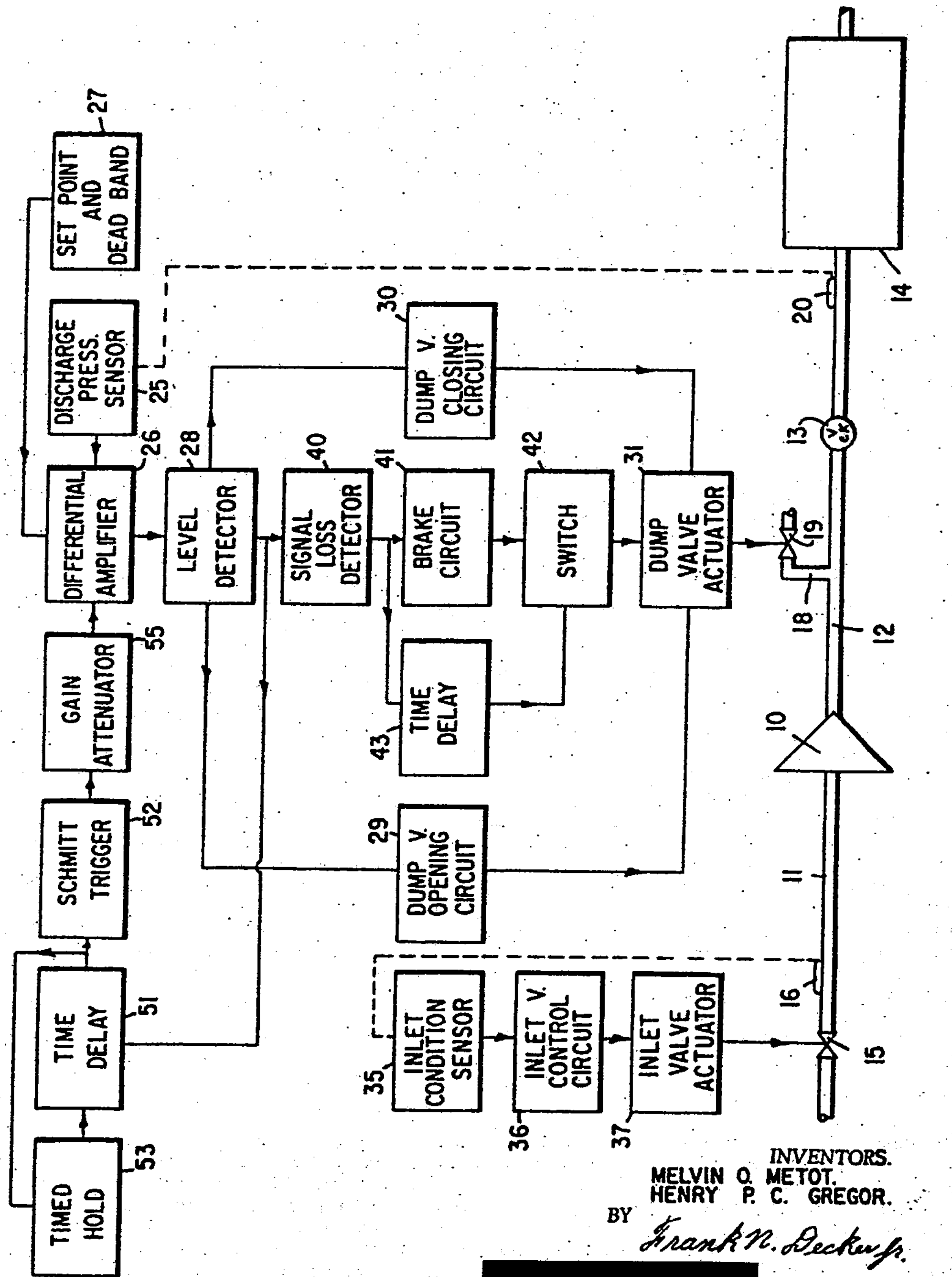
Witnesses:
HANSON C. COXE,
JOHN BAKER.

Exhibit 10

Nov. 19, 1968 M. O. METOT ET AL 3,411,702

CONTROLLING GAS COMPRESSION SYSTEMS

Filed March 13, 1967



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PTX 1006

United States Patent Office

3,411,702
Patented Nov. 19, 1968

1

3,411,702

CONTROLLING GAS COMPRESSION SYSTEMS

Melvin O. Metot, Canastota, and Henry P. C. Gregor, Syracuse, N.Y., assignors to Carrier Corporation, Syracuse, N.Y., a corporation of Delaware

Filed Mar. 13, 1967, Ser. No. 622,545
10 Claims. (Cl. 230—7)

ABSTRACT OF THE DISCLOSURE

A gas compression system having a control system for maintaining a constant discharge gas pressure. The control employs circuitry for positioning a discharge gas dump valve in a manner to maintain the required discharge gas pressure. A motor controlling the dump valve is continuously operated for large deviations from the set point gas pressure and is intermittently repositioned with a full voltage signal for smaller deviations from the set point pressure. The length of the control signal pulses to the motor may be reduced as a function of the closeness to the set point pressure in order to slow the average speed of the adjustment as the control point is reached.

Background of the invention

This application relates to controlling gas compression systems, and more particularly to a method and apparatus for regulating the discharge pressure of a gas compression system.

A gas compression system of the type referred to herein may supply compressed air from a suitable compressed air receiver to various pneumatic tools or pneumatic control systems requiring a source of compressed air having a relatively uniform pressure. The system may employ a centrifugal air compressor which discharges compressed air into the receiver and a dump valve for venting compressed air from the system which is modulated or actuated by a control system so as to maintain a uniform receiver air pressure.

In such systems, it is desirable to provide relatively rapid actuation of the dump valve when the receiver air pressure differs substantially from the desired pressure and to slow down the rate of change of the dump valve when the receiver air pressure is close to the desired pressure so that the system avoids "hunting." While a control system having such a characteristic is desirable, it is generally costly to provide. For example, inexpensive alternating current electrical motors are not easily controlled because their torque-speed characteristic is such that when their speed is reduced by reducing the average voltage or current supplied to them, they may have insufficient torque to accurately position the dump valve over the required range because the motor will stall. This problem may be overcome by using certain types of electrical controls, but prior systems for achieving this result have involved unacceptably complex and expensive control circuitry or mechanism.

Summary of the invention

In accordance with a preferred embodiment of this invention, a control circuit is provided for positioning the dump valve which employs an inexpensive alternating current, valve actuator motor. A compressed discharge gas pressure sensor provides a compressed gas pressure signal which is compared against a desired set point pressure signal to provide an error signal having a magnitude corresponding to the difference between the actual pressure and the desired pressure. The error signal is passed to a level detector which responds to an error signal level indicative of a need to reposition the dump valve. The level detector transmits a control signal to a dump valve opening circuit and a dump valve closing circuit to properly position the dump valve actuator motor upon detection of the predetermined error signal level.

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Upon the termination of the control signal from the level detector, a braking circuit is actuated to transmit a braking signal to the dump valve actuator to stop the actuator and thereby prevent excessive hunting or overshoot of the dump valve.

A time delay circuit is provided to switch off the braking signal a relatively short time after its occurrence so that the dump valve actuator is not overheated by the continued presence of a brake signal.

In addition, an error signal attenuator circuit is provided which attenuates the error signal after a period of time following the occurrence of a control signal from the level detector. Consequently, as the dump valve closely approaches the position at which the proper set point pressure is achieved in the system, the attenuated error signal will eventually be reduced to a level which is insufficient to provide a control signal output from the level detector and the braking circuit will stop the dump valve actuator. A timed holding circuit is provided to continue to attenuate the error signal for a period of time after the occurrence of the control signal output from the level detector. After this period of time has elapsed, the attenuator is switched out of the control circuit so that another control signal can be supplied from the error signal level detector in the event that the unattenuated error signal has a level great enough to provide a control signal output from the level detector. The sequence of providing a control signal, switching in the attenuator for a period of time, braking the dump valve actuator, and thereafter switching the attenuator out of the circuit is repeated until the dump valve reaches a position so that the error signal is within a preselected dead band indicative of no further need of repositioning the dump valve. The length of the control signal may be proportionally reduced as the dead band is approached to give a more precise control characteristic.

By employing the control system and method described herein, the dump valve is quickly repositioned to a new required position but is slowed down as the compressed gas discharge pressure of the system reaches the set point pressure. However, in the event that the error signal is large, the dump valve actuator will be quickly moved toward the new required position because the error signal, even in its attenuated condition, is large enough to provide full voltage control signal output from the level detector. An important advantage of the arrangement described is that the dump valve actuator may be a simple alternating current motor such as a permanent split capacitor motor which provides full torque output at all times when it is energized and is immediately braked when the control signal to the motor is removed.

Brief description of the drawings

The figure is a schematic block diagram illustrating the control functions employed to achieve the objects of this invention in a gas compression system.

Description of the preferred embodiment

Referring particularly to the figure, there is shown a gas compression system employing a centrifugal compressor 10 having an inlet passage 11 for ambient air and a discharge passage 12 for passing compressed air through a check valve 13 into a receiver 14 for distribution to various pneumatically operated equipment requiring a source of uniform high pressure air. A modulating inlet valve 15 is provided in inlet line 11 to regulate the passage of air to compressor 10. A bypass line 18 is connected into discharge line 12 and is provided with a modulating dump valve 19 for regulating the discharge

pressure in receiver 14 by venting compressed air. A suitable location 16 is provided for inlet air condition sensors, and a suitable location 20 is provided for a compressed discharge pressure sensor.

A main control is provided for dump valve 19 which is responsive to a compressed discharge gas pressure sensor 25, such as a pressure transducer, positioned at location 20. The compressed gas discharge pressure sensor 25 provides a discharge pressure signal which is a function of sense discharge gas pressure to a differential amplifier 26. A set point signal which is functionally related to the desired discharge gas pressure in receiver 14 is provided by circuit 27 which provides a set point signal to differential amplifier 26. In addition, a suitable dead band signal may be provided to differential amplifier 26 by circuit 27 to provide a range of discharge pressures which are sufficiently close to the desired set point pressure so that no adjustment of dump valve 19 is required.

Differential amplifier 26 compares the discharge gas pressure signal with the set point pressure signal and provides an error signal to level detector 28 which is a function of the difference between the desired pressure and the sensed pressure in receiver 14. Level detector 28 provides a dump valve opening signal or a dump valve closing signal to dump valve opening and closing circuits 29 and 30 in the event that the error signal from differential amplifier 26 exceeds a predetermined level indicative of a need to reposition the dump valve. Dump valve opening circuit 29 and dump valve closing circuit 30 in turn provide an opening or closing signal to dump valve actuator 31 which repositions dump valve 19.

In the preferred embodiment of this invention, level detector 28 may comprise a Schmitt trigger which provides a dump valve opening signal or closing signal to gate a bi-directional gated switch such as a Triac in either the dump valve opening or closing circuit. Dump valve actuator 31 preferably comprises a permanent split capacitor motor arranged so that when current passes directly from the Triac in opening circuit 29 to one of its windings and through a capacitor to the other of its windings, the motor moves in a direction to open the dump valve and the reverse function takes place when the Triac in closing circuit 30 is gated.

In addition, the main control circuit may employ an inlet air density control which modulates the position of inlet valve 15 to compensate for variations in the density of inlet air to compressor 10. This control may employ suitable inlet condition sensors 35 responsive to temperature and pressure of the inlet air which provide an inlet air condition signal to an inlet valve control circuit 36 which in turn provides a control signal to inlet valve actuator 37 to properly position valve 15.

In accordance with this invention, additional control circuits are provided to brake dump valve actuator 31 upon the termination of a control signal from level detector 28, and to slow the operation of dump valve actuator 31 as the set point pressure is approached.

To achieve the braking function, level detector 28 provides a control signal to signal loss detector 40 whenever a control signal is passed to dump valve opening circuit 29 or dump valve closing circuit 30. Upon the termination of the control signal from level detector 28, the signal loss detector 40 passes a control signal to brake circuit 41. Brake circuit 41 in turn passes a braking signal through a normally closed switch 42 to dump valve actuator 31. The presence of a braking signal on dump valve actuator 31 immediately stops further adjustment of dump valve 19 to prevent it from overshooting the desired position, thereby overcoming inertial effects in the actuator.

In addition, the control signal from signal loss detector 40 is passed through a time delay circuit 43 which opens switch 42 a predetermined short length of time after the occurrence of a control signal from signal loss detector 40, or in other words after the termination of a control signal from level detector 28. Opening of switch 42 terminates the braking signal to dump valve actuator 31 to prevent overheating of the dump valve actuator.

Signal loss detector 40 may simply comprise a transistor which passes direct current through brake circuit 41 and switching circuit 42 to the winding of the motor in dump valve actuator 31 causing the motor to stop. Switch 42 may comprise a silicon-controlled rectifier which both controls the passage of the braking current and serves to rectify an alternating current to provide the direct current required for the braking signal. Time delay circuit 43 may comprise a resistance-capacitance circuit having a time constant which serves to remove a positive voltage from the gate of the silicon-controlled rectifier in switch 42 from brake circuit 41 to switch the silicon-controlled rectifier to a nonconducting state after about four cycles of rectified alternating current having passed to dump valve actuator 31.

The slowing of the dump valve actuator as the desired set point pressure is approached is achieved by additional circuitry which is also actuated by a control signal output from level detector 28. The control signal output is supplied to a time delay circuit 51 which provides a delayed control signal to a Schmitt trigger 52. In addition, the delayed signal from time delay circuit 51 is supplied to a timed holding circuit 53 which continues to supply the signal from time delay circuit 51 to actuate the Schmitt trigger for a period of time after the termination of the control signal output from level detector 28. Schmitt trigger 52 supplied control signal to switch a gain attenuator 55 into differential amplifier circuit 26 to attenuate the gain of the differential amplifier.

Time delay circuit 51 and timed holding circuit 53 may comprise a resistance-capacitance network supplying the control signal to Schmitt trigger 52. The resistance-capacitance network is arranged so that one period of time is required to charge the capacitor to a voltage sufficient to actuate Schmitt trigger 52 and a second period of time is required to discharge the capacitor sufficiently to deenergize Schmitt trigger 52, thereby providing the timed holding function. Gain attenuator 55 may comprise a resistive network which is switched into differential amplifier 26 by energizing Schmitt trigger 52 so as to reduce the gain of the differential amplifier, which has the effect of widening the effective dead band of the control system for the period of time that the gain attenuator affects the output of differential amplifier 26.

In describing an example of the operation of the control system, it will be assumed that the pressure sensed by pressure sensor 25 indicates that receiver 14 is substantially below the desired set point pressure. In this event, differential amplifier 26 will provide a high level error signal output due to the large difference between the sensed discharge pressure and the desired set point pressure. This high level error signal is transmited from differential amplifier 26 to level detector 28. Level detector 28 detects the existence of a high level error signal and transmits a control signal to dump valve closing circuit 30 which in turn transmits a dump valve closing circuit signal to dump valve actuator 31 to reposition dump valve 19 and reduce the quantity of compressed air vented from the system. At the same time, a control signal from level detector 28 passes to time delay circuit 51. After a period of time, time delay circuit 51 passes a control signal to Schmitt trigger 52 which the switches gain attenuator 55 into the differential amplifier circuit. The switching of gain attenuator 55 into the differential amplifier will attenuate the error signal supplied to level detector 28. However, if the difference between the sensed discharge gas pressure and the set point pressure is large, level detector 28 will still receive an error signal of a sufficiently large magnitude, even in its attenuated condition, to indicate a need for adjustment of dump valve 19. Consequently, level detector 28 will continue to provide a control signal output to dump valve closing circuit 30

and dump valve actuator will continue to close at full speed. Also, the control signal output of level detector 28 will continue to be supplied through time delay circuit 51 to Schmitt trigger 52 and gain attenuator 55 will remain in the differential amplifier circuit.

As dump valve 19 continues to close and the pressure in receiver 14 rises to approach the set point pressure, the attenuated error signal output from differential amplifier 26 will continuously decrease until it is reduced to a level below that at which level detector 28 provides a control signal output. When the control signal output from level detector 28 is terminated, signal loss detector 40 will provide a braking signal to dump valve actuator 31 as previously described. However, gain attenuator circuit 55 will remain in differential amplifier circuit 26 for a period of time determined by timed holding circuit 53.

After a period of time following the termination of a control signal from level detector 28, timed holding circuit 53 and time delay circuit 51 no longer supply a control signal to Schmitt trigger 52 and gain attenuator 55 is switched out of the circuit of differential amplifier 26. Consequently, the error signal is passed to level detector 28 in an unattenuated condition. If the unattenuated error signal has a magnitude of the predetermined level required to provide a control signal output from level detector 28, another control signal will be provided to dump valve closing circuit 30, which will again actuate dump valve actuator 31. Again, the control signal output from level detector 28 is supplied after a period of time through time delay circuit 51 to Schmitt trigger 52, thereby switching gain attenuator 55 back into the circuit of differential amplifier 26. Assuming that the difference between the sensed discharge gas pressure and the set point pressure is now relatively small, the attenuated error signal will again be insufficient to produce a control signal output from level detector 28 and dump valve actuator 31 will be braked and gain attenuator circuit 55 will remain in the differential amplifier circuit for a period of time determined by timed holding circuit 53.

The described sequence of events will continue to be repeated so that dump valve actuator 31 will be moved for a period of time in the opening direction, will then be braked, and will continue to be deenergized for a period of time. This sequence will continue until the unattenuated error signal from differential amplifier 26 decreases to a level which will no longer cause level detector 28 to provide a control signal output. It will be apparent, therefore, that dump valve 19 will continue to close until the pressure in receiver 14 reaches a pressure within the dead band provided by circuit 27, at which time no further adjustment of the dump valve is required.

It may be desirable to provide a timing means in the circuit of differential amplifier 26 so that the length of time that the error signal is on is varied as a function of the closeness of the discharge pressure to the dead band or set point pressure. Under these conditions, the length of the error signal and the resulting control signal is reduced as the set point pressure is approached so as to reduce the average speed of the dump valve actuator when the system is near the set point or dead band pressure. This provides a more stable proportional control characteristic which reduces hunting and overshooting of the system. In practice, the result can be achieved by adding capacitance between branches of differential amplifier 26 so that the capacitor introduces a time constant due to its charging rate. When a relatively smaller error signal is present, a longer time will be required before a signal output from the differential amplifier will reach a point sufficient to provide a control signal output from level detector 28 due to the increased length of time required to charge the capacitor with the smaller error signal.

In summary, the control circuit causes dump valve actuator 31 to operate at full speed in the desired direction when a large error signal is present and operates at a relatively slower average speed, occasioned by the start-stop characteristic, when a smaller error signal is present until the discharge pressure falls within the dead band of the system. In practice, gain attenuator 55 may be switched into differential amplifier 26 about 20 milliseconds after the occurrence of a control signal output from level detector 28 and may be switched out of the circuit of the differential amplifier about 200 milliseconds after the termination of a control signal output from the level detector.

Because full motor current is always supplied to dump valve actuator 31 whenever a control signal is supplied to it from opening circuit 29 or closing circuit 30, the motor will exhibit full torque to accurately move the dump valve in the desired direction. However, since the motor is sequentially turned on, braked, and deenergized, the effective motor speed will be substantially below that of its full speed condition when the set point pressure is closely approached. By employing a control system in accordance with this invention, characteristics of a complicated proportional control are simulated with a relatively simple and inexpensive alternating current motor, and the effect of hunting of the control valve is materially reduced.

While a preferred embodiment of this invention has been described for purposes of illustration, it will be understood that other electrical circuitry of well-known design may be used to implement the control functions described herein. Further, the control system described herein may be employed in a pneumatic or fluid amplifier type of control using the principles herein described. In addition, the control may be employed in gas compression apparatus other than the air compression system illustrated herein.

We claim:

1. A method of operating a gas compression system including a gas compressor and a dump valve having an actuator for maintaining a desired discharge pressure, which comprises: sensing the compressed gas discharge pressure of said system to provide a discharge pressure signal which is a function of said gas discharge pressure; providing a set point pressure reference signal corresponding with a desired compressed gas discharge pressure; comparing said gas discharge pressure signal to said set point pressure signal to provide an error pressure signal; detecting the presence of an error pressure signal having a predetermined level indicative of a need to actuate said dump valve; providing a control signal to actuate said dump valve upon detecting said predetermined error pressure signal level; attenuating said error pressure signal a predetermined period of time after the occurrence of said control signal, thereby terminating the control signal if the attenuated error pressure signal has a level less than that of said predetermined level; continuing to attenuate said error pressure signal for a time after the termination of said control signal; and removing the attenuation from said error pressure signal after said period of time has elapsed to return the control system to its initial sensitivity for again actuating said dump valve actuator for a period of time in the event that said discharge pressure is still sufficiently different from said desired compressed gas discharge pressure to provide an error signal of said predetermined level in its unattenuated condition.

2. A method of operating a gas compression system as defined in claim 1 which includes the step of applying a braking signal to brake said dump valve actuator after terminating the passage of a control signal thereto to effectively brake further movement of said dump valve.

3. A method of operating a gas compression system as defined in claim 2 including the step of terminating the braking signal to said dump valve actuator a relatively short period of time after application thereof so as to prevent excessive heating of said actuator.

4. A method of controlling a gas compression system as defined in claim 1 including the step of reducing the length of the control signal as the discharge pressure

approaches the set point pressure so as to further reduce the average speed of actuation of said dump valve as the desired pressure is approached.

5. A gas compression system for maintaining a controlled discharge pressure which comprises: a gas compressor having an inlet for gas to be compressed and an outlet for compressed gas; a dump valve for maintaining a desired compressed gas discharge pressure by venting compressed gas; a dump valve actuator for controlling said dump valve; sensing means for sensing the compressed gas discharge pressure of said system and providing a pressure signal functionally related thereto; circuit means for providing a desired set point pressure reference signal; circuit means for comparing said set point pressure reference signal to said compressed gas pressure signal to provide an error signal; a level detector for sensing the occurrence of an error signal of a predetermined magnitude and for passing a control signal to said discharge valve actuator to reposition said valve; attenuator means for selectively attenuating said error signal; time delay circuit means for actuating said attenuator means to attenuate the error signal passed to said level detector for a length of time after the occurrence of said control signal; and holding means for continuing the attenuation of said error signal for a period of time after the termination of a control signal output from said level detector to slow the operation of said dump valve control motor when the attenuated error signal is less than said predetermined magnitude, thereby reducing hunting of said dump valve as the desired compressed gas discharge pressure is approached.

6. A gas compression system as defined in claim 5 including a brake circuit for providing a braking signal to said dump valve actuator upon the termination of the passage of a control signal thereto to prevent further

movement of said dump valve in the absence of a control signal, thereby reducing hunting of said dump valve.

7. A gas compression system as defined in claim 6 including timing means for terminating the application of said braking signal to said dump valve actuator after a relatively short period of time to prevent excessive heating of said actuator.

8. A gas compression system as defined in claim 5 wherein said circuit means for comparing said set point pressure reference signal to said compressed gas pressure signal comprises a differential amplifier, and wherein said attenuator means comprises circuit means to selectively reduce the gain of said differential amplifier.

9. A gas compresison system as defined in claim 5 including circuit means for establishing a dead band pressure range about the set point pressure within which an unattenuated error signal has an insufficient magnitude to provide a control signal output from said level detector.

10. A gas compression system as defined in claim 5 including timing means for reducing the length of the control signal as the system approaches the set point pressure to further slow the average rate of actuation of said valve as the desired system pressure is approached.

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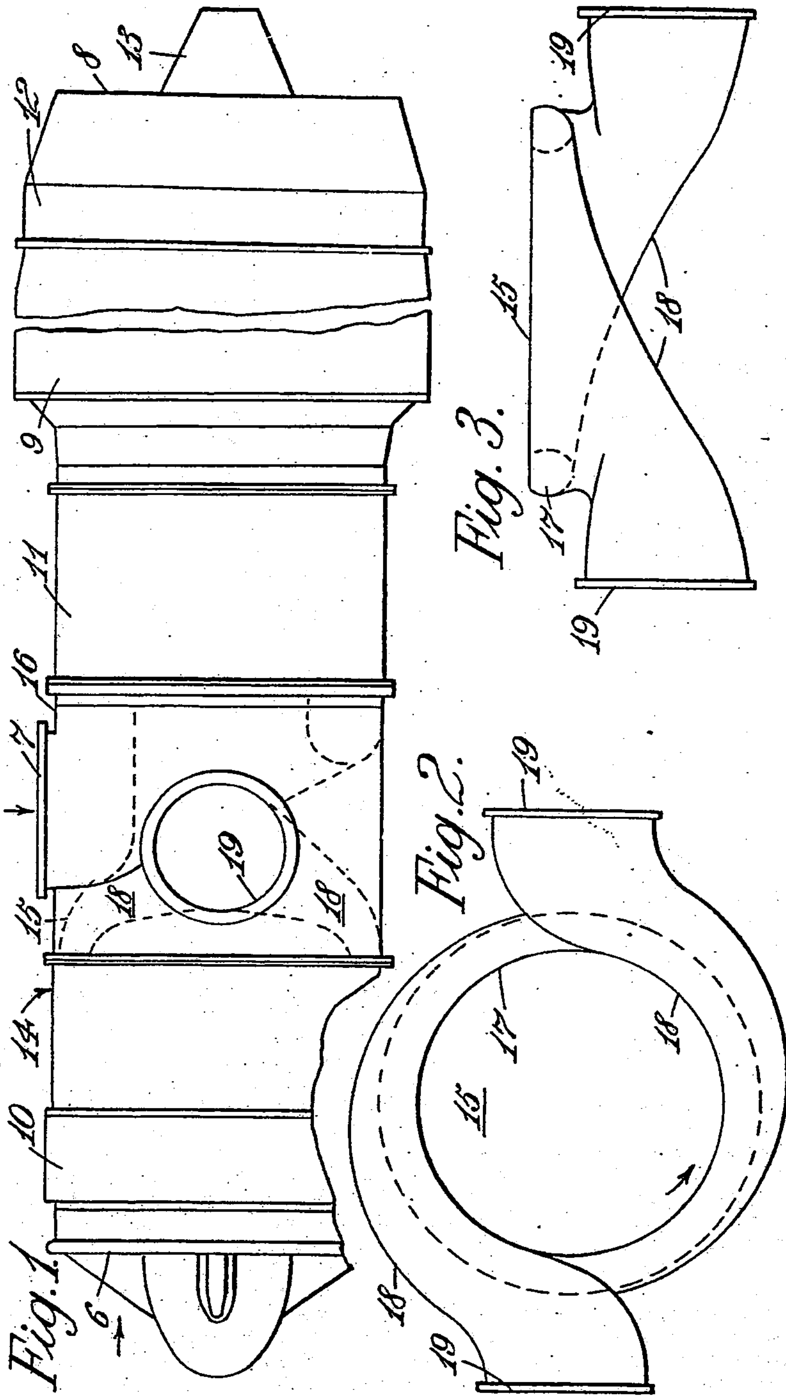
WILLIAM L. FREEH, *Primary Examiner.*

Exhibit 11

Aug. 1, 1961 G. M. LEWIS ET AL 2,994,471

AIR SUPPLY UNIT

Filed March 10, 1958



United States Patent Office 2,994,471
Patented Aug. 1, 1961

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2,994,471

AIR SUPPLY UNIT

Gordon Manns Lewis and Peter Frederick Orchard, Bristol, England, assignors, by mesne assignments, to Bristol Siddeley Engines Limited, Bristol, England, a British company

Filed Mar. 10, 1958, Ser. No. 720,220
Claims priority, application Great Britain Mar. 19, 1957
4 Claims. (Cl. 230—116)

This invention relates to air supply units for supplying substantial quantities of compressed air, and concerns such units which are intended for use in aircraft, for example, for blowing air over the wing control surfaces of the aircraft. However, a unit according to the invention has other applications in and other uses than in aircraft, and the term "air" as used in this specification is intended to include any gaseous medium.

According to the invention an air supply unit comprises an axial flow load compressor, a gas turbine engine having an axial flow compressor, said engine being connected to drive said load compressor, and said load compressor being arranged coaxially with the axial flow compressor of said engine and on the side thereof remote from the turbine system of the engine, and deflection ducting connected to receive the discharge from said load compressor, and to deflect the discharge outwardly in a lateral direction with respect to the axis of the load compressor, said ducting being located between said load compressor and said engine.

According to a feature of the invention, the turbine system of the engine may comprise a single turbine, in which case the turbine is connected to drive the engine compressor and the load compressor.

When this feature is adopted it is preferred that the engine compressor and the load compressor have matching flow characteristics and are each connected to be driven directly by said turbine, for example through a common driving shaft. In this way the complication of reduction gearing is avoided.

The turbine system may, however, according to an alternative feature of the invention, comprise a pair of mechanically independent turbines one of which is connected to drive the engine compressor and the other of which is connected to drive the load compressor.

In the case of an air supply unit according to the invention intended for use in an aircraft, it is preferred that said engine is a gas turbine jet propulsion engine. The air supply unit may then be used to propel the aircraft as well as supply air for purposes which may include propulsion.

According to another feature of the present invention, the load compressor may have a straight annular air intake duct arranged co-axially with the load compressor, and the engine compressor may have an air intake located between said deflection ducting and the engine compressor. Where the unit is incorporated in an aircraft the air intake duct for the load compressor may lead from a forwardly facing annular air intake of the kind normally associated with the engine compressor.

According to another feature of the invention, the deflection ducting may comprise an annular portion co-axial with the load compressor and connected to receive directly through an annular outlet from the load compressor air compressed in the load compressor, at least one laterally directed discharge passage, and for each discharge passage a part spiral passage winding from said annular portion to the discharge passage in the direction of rotation of the load compressor. This arrangement of the ducting utilises the swirl of the air discharged by the load compressor to minimise the change of direction which the deflection ducting has to impart to the air discharging from the load compressor in order to deflect it outwardly in the lateral direction.

2

One embodiment of the present invention will now be described, merely by way of example, with reference to

FIGURE 1 is a diagrammatic side elevation of an air supply unit according to the invention intended for use in an aircraft,

FIGURE 2 is an end elevation on a larger scale of the deflection ducting, and

FIGURE 3 is a sectional elevation corresponding to FIGURE 2.

Referring to FIGURE 1, the unit comprises a gas turbine jet propulsion engine comprising an axial flow compressor 11, a combustion system 9 and a turbine system 12. The jet stream issuing from the turbine system emerges through an annular outlet 8 around an exhaust cone 13, and, when the unit is installed in an aircraft would be directed into a jet pipe terminating in a jet propulsion nozzle.

The air supply unit further comprises an axial flow load compressor 14 co-axial with the compressor 11 and on the side thereof remote from the turbine system 12 and deflection ducting 15 connected to receive the discharge from the compressor 14 and to deflect the discharge outwardly in a lateral direction with respect to the axis of the compressor 14. For convenience the term "laterally directed" will hereinafter be used to mean directed laterally with respect to the axis of the compressor 14, and in a similar way the term "axially directed" will be used to mean directed in the direction of the axis of the compressor 14.

The compressor 14 has a straight annular air intake duct 10 arranged co-axially therewith and leading from an axially directed air intake opening 6, and the the compressor 11 has a laterally directed air intake opening 7 opening into an axially directed annular air intake duct 16 co-axial with the engine compressor. The duct 16 is located between the deflection ducting 15 and the compressor 11. The turbine system 12 comprises only a single turbine, and the compressor 14 is coupled to rotate with the compressor 11 which is in turn connected to be driven by the turbine. The compressor 14 and the compressor 11 have matching flow characteristics and are each driven directly by the turbine. By matching the flow characteristics of the two compressors, the compressors can be driven at the same speed and the problems involved by the use of reduction gearing are avoided.

In an alternative arrangement, the turbine system 12 may comprise two mechanically independent turbines arranged in flow series, the high pressure turbine being connected to drive the compressor 11 and the low pressure turbine connected to drive the compressor 14. As will readily be understood the low pressure turbine receives as its working medium the combustion gases discharging from the high pressure turbine, and the two turbines are arranged co-axially with one another, the low pressure turbine driving the compressor 14 by means of a shaft which passes through a hollow drive shaft connecting the high pressure turbine with the compressor 11, and through the compressor 11.

The form of the deflection ducting 15 is shown more clearly in FIGURES 2 and 3 to which reference will now be made. The deflection ducting comprises an annular portion 17 co-axial with the compressor 14 and connected to receive directly through an annular outlet from the compressor 14 air compressed in the compressor 14. Winding from the annular portion 17 in the direction of rotation of the compressor 14 to two laterally directed discharge passages 19 located diametrically opposite one another are two part-spiral diffusers 18.

The direction of winding of the part-spiral diffuser

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portions 18 is made the same as the direction of rotation of the compressor 14 so as to match the direction of swirl of compressed air discharged from the compressor 14 in order to minimise the deflection which has to be imparted to the discharge by the walls of the diffuser portions in order to deflect the discharge outwardly through the laterally directed discharge passages 19.

In an alternative arrangement, diffuser portions 18 may be dispensed with, and an annular diffuser may be inserted co-axial with the compressor 14, the annular diffuser being connected to receive the discharge of the compressor 14 directly through said annular outlet. In this case the deflection ducting would comprise an annular portion such as 17 communicating with the downstream end of the annular diffuser and one or more laterally directed discharge passages such as 19 communicating directly with the annular portion. The advantage of the part-spiral diffuser arrangement illustrated however is that it is more compact, and does not occupy so much axial space as the alternative arrangement.

The annular air intake duct 16 and the annular portion 17 of the deflection ducting 15 surround the drive shaft of the compressor 14.

Instead of providing two discharge passages 19 and two part-spiral portions 18, there may be a single discharge passage 19 connected with the portion 17 by a single part-spiral passage 18, and furthermore, the single passage 19 may be directed oppositely to the air intake opening 7 instead of at right angles thereto.

An axial flow gas turbine jet propulsion engine may readily be converted into an air supply unit as described, by inserting between the air intake casing of the engine and the compressor casing of the engine a load compressor section, and a section comprising deflection ducting such as 15 and an alternative air intake arrangement for the compressor of the engine, the engine air intake being used to feed the load compressor instead of the engine compressor, and the load compressor being connected to be driven with the engine compressor by an extension drive shaft on the engine compressor.

We claim:

1. An air supply unit comprising a gas turbine engine including an axial flow engine compressor having an air inlet open directly to atmosphere, combustion equipment connected to receive compressed air from the compressor, and a turbine system connected to receive the products of combustion from the combustion equipment, an axial flow load compressor arranged coaxially with the engine compressor and on the side thereof remote from the turbine system of the engine, coupling means drivingly connecting the engine to said load compressor, said load compressor having an annular outlet duct between the engine compressor and the load compressor and encircling the engine axis, and deflection ducting providing a discharge outlet for air compressed in the load compressor, said deflection ducting forming a part-spiral passage which is connected to receive compressed air from the outlet duct of the load compressor and which winds from said annular outlet duct to said discharge outlet in the direction of rotation of the load compressor.

2. An air supply unit as claimed in claim 1, wherein the load compressor has a co-axial straight annular air intake duct leading from an axially directed air intake opening for the load compressor, and the engine compressor has a laterally directed air intake aperture open directly to atmosphere and leading into an axially directed annular air intake duct for the engine compressor located between said deflection ducting and the engine compressor and co-axial with the engine compressor.

3. An air supply unit as claimed in claim 1, wherein said part-spiral passage is shaped to act as a diffuser.

4. An air supply unit comprising a gas turbine engine including an axial flow engine compressor having an air inlet open directly to atmosphere, combustion equipment connected to receive compressed air from the compressor, and a turbine system connected to receive the products of combustion from the combustion equipment, an axial flow load compressor arranged coaxially with the engine compressor and on the side thereof remote from the turbine system of the engine, said load compressor having an annular outlet duct which is disposed between the engine compressor and the load compressor and which encircles the engine axis, deflection ducting providing a discharge outlet for air compressed in the load compressor, said deflection ducting forming a part-spiral passage which is connected to receive compressed air from the outlet duct of the load compressor and which winds from said annular outlet duct to said discharge outlet in the direction of rotation of the load compressor, and a drive shaft drivingly connecting the engine to said load compressor, said drive shaft being encircled by the deflection ducting.

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Exhibit 12

IN THE UNITED STATES DISTRICT COURT
FOR DISTRICT OF DELAWARE

HONEYWELL INTERNATIONAL INC., and HONEYWELL INTELLECTUAL PROPERTIES INC.,

Plaintiffs,

v.

HAMILTON SUNDSTRAND CORP.,

Defendant.

C.A. No. 99-309-GMS

HAMILTON SUNDSTRAND'S RESPONSE TO PLAINTIFFS' FIRST SET OF REQUESTS FOR ADMISSION

Defendant, Hamilton Sundstrand Corp. ("HSC") responds to plaintiffs, Honeywell International, Inc.'s and Honeywell Intellectual Properties Inc.'s (collectively, "Honeywell") first set of requests for admission, as follows:

HSC'S GENERAL OBJECTIONS

1. HSC objects to each request for admission to the extent it calls for information that is protected by privilege from discovery under the attorney-client communication privilege, the attorney work product doctrine, or any other applicable privilege. Nothing contained in these responses shall be deemed a waiver of any privilege.

2. HSC objects to all Honeywell's Definitions, Instructions and Requests to the extent they seek to impose duties beyond those required by the Federal Rules of Civil Procedure, the Local Rules, or the rules of this Court.

REMAND
PTX 1021

3. HSC objects to Honeywell's definition of the terms "Sundstrand APS 3200," "APS 3200" and "Accused Product" to the extent they cover any versions or variations of that APU beyond the product on which the original jury verdict in this case was based.

4. HSC objects to Honeywell's definition of the term "Asserted Equivalent" as vague and ambiguous.

5. HSC objects to each Request for Admission as premature to the extent it calls for the disclosure of expert testimony.

RESPONSES

1. Prior to August 30, 1983, no surge control system in any APU or other industrial or aerospace application resolved the "inverted-V/double-solution" in the same way as the "inverted-V/double-solution" was later resolved in the APS 3200 APU.

RESPONSE: HSC incorporates its general objections. HSC objects to this request for admission as premature to the extent it calls for the disclosure of expert testimony. Subject to and without waiving its objections, HSC denies this request.

2. Prior to August 30, 1983, no surge control system in any APU or other industrial or aerospace application utilized inlet guide vanes in surge control systems in the same way as inlet guide vanes were used in the surge control system of the APS 3200 APU.

RESPONSE: HSC incorporates its general objections. HSC objects to this request for admission as premature to the extent it calls for the disclosure of expert testimony. HSC also objects to this request for admission because it fails to identify what is meant by "the same way as inlet guide vanes were used in the surge control system of the APS 3200 APU." Subject to and without waiving its objections, HSC denies this request.

3. Sundstrand began developing the surge control system used in its APS 3200 after August 30, 1983.

RESPONSE: Subject to and without waiving its general objections, HSC admits that Sundstrand began developing the surge control system on the APS 3200 after August 30, 1983, but notes that the surge control system for the APS 3200 incorporated elements developed prior to the Relevant Amendment Dates.

4. Sundstrand's particular use of inlet guide vane position in the surge control system of the APS 3200 APU is not described elsewhere in patents or Prior Art.

RESPONSE: HSC incorporates its general objections. Subject to and without waiving its objections, HSC denies the request.

5. During the prosecution of the Patents-In-Suit, the Examiner did not make any mention of any Prior Art references that disclose inlet guide vanes or the use of their position as part of a surge control system.

RESPONSE: Subject to and without waiving its objections, HSC admits that during the prosecution of the Patents-In-Suit, the Examiner did not reference any Prior Art that disclosed inlet guide vanes or the use of their position as part of a surge control system, but notes that considerable Prior Art that was *not* presented to the Examiner during the prosecution of the Patents-In-Suit does disclose the use of inlet guide vanes as part of a surge control system.

October 11, 2005

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Exhibit 13

MANUAL OF PATENT EXAMINING PROCEDURE

Original Fourth Edition, dated June 1979

U.S. DEPARTMENT OF COMMERCE • PATENT AND TRADEMARK OFFICE

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Second Edition, November 1953
Revision 1, April 1955
Revision 2, June 1956
Revision 3, June 1957
Revision 4, July 1958
Third Edition, November 1961
Revision 1, January 1964
Revision 2, November 1964
Revision 3, January 1965
Revision 4, April 1965
Revision 5, July 1965
Revision 6, October 1965
Revision 7, January 1966
Revision 8, April 1966
Revision 9, July 1966
Revision 10, October 1966
Revision 11, January 1967
Revision 12, April 1967
Revision 13, July 1967
Revision 14, October 1967
Revision 15, January 1968
Revision 16, April 1968
Revision 17, July 1968
Revision 18, October 1968
Revision 19, January 1969
Revision 20, April 1969
Revision 21, July 1969
Revision 22, October 1969
Revision 23, January 1970
Revision 24, April 1970
Revision 25, July 1970
Revision 26, October 1970
Revision 27, January 1971
Revision 28, April 1971
Revision 29, July 1971
Revision 30, October 1971
Revision 31, January 1972
Revision 32, April 1972
Revision 33, July 1972
Revision 34, October 1972
Revision 35, January 1973
Revision 36, April 1973
Revision 37, July 1973
Revision 38, October 1973
Revision 39, January 1974
Revision 40, April 1974
Revision 41, July 1974
Revision 42, October 1974
Revision 43, January 1975
Revision 44, April 1975
Revision 45, July 1975
Revision 46, October 1975
Revision 47, January 1976
Revision 48, April 1976
Revision 49, July 1976
Revision 50, October 1976
Revision 51, January 1977
Revision 52, April 1977
Revision 53, July 1977
Revision 54, October 1977
Revision 55, January 1978
Revision 56, July 1978
Fourth Edition, June 1979

and when possible he should offer a definite suggestion for correction.

If the examiner is satisfied after the search has been completed that patentable subject matter has been disclosed and the record indicates that the applicant intends to claim such subject matter, he may note in the Office action that certain aspects or features of the patentable invention have not been claimed and that if properly claimed such claims may be given favorable consideration.

37 CFR 1.112. Reexamination and reconsideration. After response by applicant (section 1.111) the application will be reexamined and reconsidered, and the applicant will be notified if claims are rejected, or objections or requirements made, in the same manner as after the first examination. Applicant may respond to such Office action, in the same manner provided in section 1.111 with or without amendment, but any amendments after the second Office action must ordinarily be restricted to the rejection or to the objections or requirements made, and the application will be again considered, and so on repeatedly, unless the examiner has indicated that the action is final.

706.01 Contrasted With Objection

The refusal to grant claims because the subject matter as claimed is considered unpatentable is called a "rejection." The term "rejected" must be applied to such claims in the examiner's letter. If the form of the claim (as distinguished from its substance) is improper, an "objection" is made. The practical difference between a rejection and an objection is that a rejection, involving the merits of the claim, is subject to review by the Board of Appeals, while an objection, if persisted in, may be reviewed only by way of petition to the Commissioner.

An example of a matter of form as to which objection is made is dependency of a claim on a rejected claim, if the dependent claim is otherwise allowable. See § 608.01(n).

706.02 Rejection on Prior Art

35 U.S.C. 102. Conditions for patentability; novelty and loss of right to patent. A person shall be entitled to a patent unless—

(a) the invention was known or used by others in this country, or patented or described in a printed publication in this or a foreign country, before the invention thereof by the applicant for patent, or

(b) the invention was patented or described in a printed publication in this or a foreign country or in public use or on sale in this country, more than one year prior to the date of the application for patent in the United States, or

(c) he has abandoned the invention, or

(d) the invention was first patented or caused to be patented, or was the subject of an inventor's certificate, by the applicant or his legal representatives or assigns in a foreign country prior to the date of the application for patent in this country on an application for patent or inventor's certificate filed more than twelve months before the filing of the application in the United States, or

(e) the invention was described in a patent granted on an application for patent by another filed in the United States before the invention thereof by the applicant for patent, or

(f) he did not himself invent the subject matter sought to be patented, or

(g) before the applicant's invention thereof the invention was made in this country by another who had not abandoned, suppressed, or concealed it. In determining priority of invention there shall be considered not only the respective dates of conception and reduction to practice of the invention, but also the reasonable diligence of one who was first to conceive and last to reduce to practice, from a time prior to conception by the other.

35 U.S.C. 103. Conditions for patentability; non-obvious subject matter. A patent may not be obtained though the invention is not identically disclosed or described as set forth in section 102 of this title, if the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains. Patentability shall not be negatived by the manner in which the invention was made.

By far the most frequent ground of rejection is on the ground of unpatentability in view of the prior art, that is, that the claimed matter is either not novel under 35 U.S.C. 102, or else it is obvious under 35 U.S.C. 103. The language to be used in rejecting claims should be unequivocal. See § 707.07(d).

35 U.S.C. 102 (Anticipation or Lack of Novelty)

The distinction between rejections based on 35 U.S.C. 102 and those based on 35 U.S.C. 103 should be kept in mind. Under the former, the claim is anticipated by the reference. No question of obviousness is present. It may be advisable to identify a particular part of the reference to support the rejection. If not, the expression "rejected under 35 U.S.C. 102 as clearly anticipated by" is appropriate.

35 U.S.C. 103 (Obviousness)

In contrast, 35 U.S.C. 103 authorizes a rejection where to meet the claim, it is necessary to modify a single reference or to combine it with

one or more others. After indicating that the rejection is under 35 U.S.C. 103, there should be set forth (1) the difference or differences in the claim over the applied reference(s), (2) the proposed modification of the applied reference(s) necessary to arrive at the claimed subject matter, and (3) an explanation why such proposed modification would be obvious.

Prior art rejections should ordinarily be confined strictly to the best available art. Exceptions may properly be made, e.g., (1) where the propriety of a 35 U.S.C. 102 rejection depends on a particular interpretation of a claim; (2) where a claim is met only in terms by a reference which does not disclose the inventive concept involved; or (3) where the most pertinent reference seems likely to be antedated by a 37 CFR 1.131 affidavit or declaration. Such rejections should be backed up by the best other art rejections available. Merely cumulative rejections; i.e., those which would clearly fall if the primary rejection were not sustained, should be avoided.

The Court of Customs and Patent Appeals has held that expedients which are functionally equivalent to each other are not necessarily obvious in view of one another. In re Scott, 139 USPQ 297, 51 CCPA 747 (1963); In re Flint, 141 USPQ 299, 51 CCPA 1230 (1964).

This Court has also held that when a claim is rejected under 35 U.S.C. 103, a limitation which is considered to be indefinite cannot be properly disregarded. If a limitation in a claim is considered to be indefinite, the claim should be rejected under 35 U.S.C. 112, second paragraph. In re Wilson, 165 USPQ 494, 57 CCPA 1029 (1970). Note also In re Steele, 134 USPQ 292, 49 CCPA 1295 (1962). See § 706.03(d).

Where a reference is relied on to support a rejection, whether or not in a "minor capacity" that reference should be positively included in the statement of the rejection. See In re Hoch, 166 USPQ 406, 57 CCPA 1292, footnote 3 (1970).

Where the last day of the year dated from the date of publication falls on a Saturday, Sunday or holiday, the publication is not a statutory bar under 35 U.S.C. 102(b) if the application was filed on the next succeeding business day. Ex parte Olah and Kuhn, 131 USPQ 41 (Bd.App. 1960). It should also be noted that a magazine is effective as a printed publication under 35 U.S.C. 102(b) as of the date it reached the addressee and not the date it was placed in the mail. Protein Foundation Inc. v. Brenner, 151 USPQ 561 (D.C.D.C. 1966).

A U.S. patent may be a reference against an application even though the patent date is after the United States filing date of the application, provided the United States filing date of the patent is prior to the United States filing date of the application. It is proper to use such a patent as a basic or an auxiliary reference and such patents may be used together as basic and auxiliary references. This doctrine arose in *Alexander Milburn Co.* v. *Davis-Bournonville Co.*, 1926 C.D. 303; 344 O.G. 817; and was enacted into law by 35 U.S.C. 102(e). It was held applicable to rejections under 35 U.S.C. 103 by the U.S. Supreme Court in *Hazeltine Research, Inc. et al.* v. *Brenner*, 147 USPQ 429 (1965). See also section 715.01.

Public Law 92–34 provided for situations caused by the postal emergency which began on March 18, 1970 and ended on or about March 30, 1970. This law allows the applicant to claim an earlier filing date if delay in filing was caused by the emergency. Such earlier filing dates were printed on the patents along with the actual filing dates whenever it was possible. However, patents issued with earlier filing dates claimed under Public Law 92–34 are effective as prior art under 35 U.S.C. 102(e) only as of their actual filing dates and not as of such claimed earlier filing dates. The details of the procedure to claim the earlier date appeared at 889 O.G. 1064.

For the proper way to cite a patent issued after the filing of the application in which it is being cited, see § 707.05(e).

706.02(a) Establishing "Well Known" Prior Art

Things believed to be known to those skilled in the art are often asserted by the examiner to be "well known" or "matters of common knowledge". If justified, the examiner should not be obliged to spend time to produce documentary proof. If the knowledge is of such notorious character that judicial notice can be taken, it is sufficient so to state. In re Malcolm, 1942 C.D. 589; 543 O.G. 440. If the applicant traverses such an assertion the examiner should cite a reference in support of his position.

When a rejection is based on facts within the personal knowledge of the examiner, the data should be stated as specifically as possible, and the reference must be supported, when called for by the applicant, by an affidavit from the examiner. Such an affidavit is subject to contradiction or explanation by the affidavits of the applicant and other persons. See 37 CFR 1.107.

Failure of the applicant to seasonably challenge such assertions establishes them as admitted prior art. See In re Gunther, 1942 C.D. 332; 538 O.G. 744; In re Chevenard, 1944 C.D. 141; 500 O.G. 196. This applies also to assertions of the Board. In re Selmi, 1946 C.D.

Exhibit 14

264

IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF DELAWARE

HONEYWELL INTERNATIONAL INC., and
HONEYWELL INTELLECTUAL PROPERTY INC.,

Plaintiffs,

v.

HAMILTON SUNDSTRAND CORPORATION,

Defendant.

Case No. 99-309 (GMS)

FILED
FEB 16 2001
U.S. DISTRICT COURT
DISTRICT OF DELAWARE

SPECIAL VERDICT FORM

We, the jury, unanimously find as follows:

Infringement of U.S. Patent No. 4,428,194 ("the '194 Patent")

1. Has Honeywell shown, by a preponderance of the evidence, that Hamilton Sundstrand's APS 3200 product literally infringes Claim 4 of the '194 Patent?

   Yes ______ (for Honeywell) **No __✓__ (for Hamilton Sundstrand)**

2. Has Honeywell shown, by a preponderance of the evidence, that Hamilton Sundstrand's APS 3200 product infringes Claim 4 of the '194 Patent under the doctrine of equivalents?

   Yes __✓__ (for Honeywell) **No ______ (for Hamilton Sundstrand)**

Infringement of U.S. Patent No. 4,380,893 ("the '893 Patent")

3. Has Honeywell shown, by a preponderance of the evidence, that Hamilton Sundstrand's APS 3200 product infringes any of the following claims of the '893 Patent under the doctrine of equivalents?

Claim 8:	Yes ✓ (for Honeywell)	No ______ (for Hamilton Sundstrand)
Claim 10:	Yes ✓ (for Honeywell)	No ______ (for Hamilton Sundstrand)
Claim 11:	Yes ✓ (for Honeywell)	No ______ (for Hamilton Sundstrand)
Claim 19:	Yes ✓ (for Honeywell)	No ______ (for Hamilton Sundstrand)
Claim 23:	Yes ✓ (for Honeywell)	No ______ (for Hamilton Sundstrand)

> If you answered any portion of Questions 1, 2, or 3 "YES," please go to question 4. Otherwise, do not go further, sign this verdict form, and advise the Court Deputy that you have reached a verdict.

Validity

Anticipation

4. Has Hamilton Sundstrand shown, by clear and convincing evidence, that any of the following claims were anticipated by any single prior art reference?

'194 Patent

Claim 4:	Yes ______ (for Hamilton Sundstrand)	No ✓ (for Honeywell)

'893 Patent

Claim 8:	Yes ______ (for Hamilton Sundstrand)	No ✓ (for Honeywell)
Claim 10:	Yes ______ (for Hamilton Sundstrand)	No ✓ (for Honeywell)
Claim 11:	Yes ______ (for Hamilton Sundstrand)	No ✓ (for Honeywell)
Claim 19:	Yes ______ (for Hamilton Sundstrand)	No ✓ (for Honeywell)
Claim 23:	Yes ______ (for Hamilton Sundstrand)	No ✓ (for Honeywell)

Obviousness

5. Has Hamilton Sundstrand shown, by clear and convincing evidence, that any of the following claims is invalid for obviousness based on one or more combination of references?

'194 Patent

Claim 4: Yes ______ **(for Hamilton Sundstrand)** No ✓ **(for Honeywell)**

'893 Patent

Claim 8: Yes ______ **(for Hamilton Sundstrand)** No ✓ **(for Honeywell)**

Claim 10: Yes ______ **(for Hamilton Sundstrand)** No ✓ **(for Honeywell)**

Claim 11: Yes ______ **(for Hamilton Sundstrand)** No ✓ **(for Honeywell)**

Claim 19: Yes ______ **(for Hamilton Sundstrand)** No ✓ **(for Honeywell)**

Claim 23: Yes ______ **(for Hamilton Sundstrand)** No ✓ **(for Honeywell)**

"On Sale" Bar

6. Has Hamilton Sundstrand shown, by clear and convincing evidence, that each of Claim 4 of the '194 Patent and Claims 8, 10, 11, 19, and 23 of the '893 Patent are invalid because of the "on-sale" bar?

Yes ______ **(for Hamilton Sundstrand)** No ✓ **(for Honeywell)**

If you found a claim infringed (i.e., answered "YES") in Questions 1, 2, or 3 and found that claim valid (i.e., answered "NO") in Questions 4, 5 and 6, please go to Question 7. Otherwise, do not go further, sign this verdict form, and advise the Court Deputy that you have reached a verdict.

Willful Infringement

7. Has Honeywell shown, by clear and convincing evidence, that Hamilton Sundstrand infringed at least one of the asserted claims willfully?

Yes ✓ **(for Honeywell)** **No** ______ **(for Hamilton Sundstrand)**

Damages

8. What amount of price erosion damages, if any, do you find Honeywell has proven by a preponderance of the evidence?

Amount: $ 45,000,000

9. What amount of reasonable royalty damages do you find Honeywell has proven by a preponderance of the evidence?

Amount: $ 1,578,065

10. What rate do you find to be a reasonable royalty?

Rate: 7.5 %

You each must sign this Verdict Form:

Dated: 2/16/01

Elizabeth M. Spallutto (Foreperson)

Erica M. Torres

Phyllis M. Haynes

[illegible]

Louis H. Jackson

Dorothy H. Eskridge

Sherry E. Hall

[illegible] Smith

EXHIBIT 15

FULLY REDACTED